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Proposal to Measure the Neutral to Charged Current Ratio for Electron Neutrinos

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Summary of Proposal

Beam: ν_e beam from $K_L^o \rightarrow \pi e \nu$ decays

Detector: 15 ft chamber filled with heavy neon

Protons: 2×10^{13} protons/pulse incident on target
400 GeV or higher

Exposure: 250,000 pictures (5×10^{18} protons)

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I. Introduction

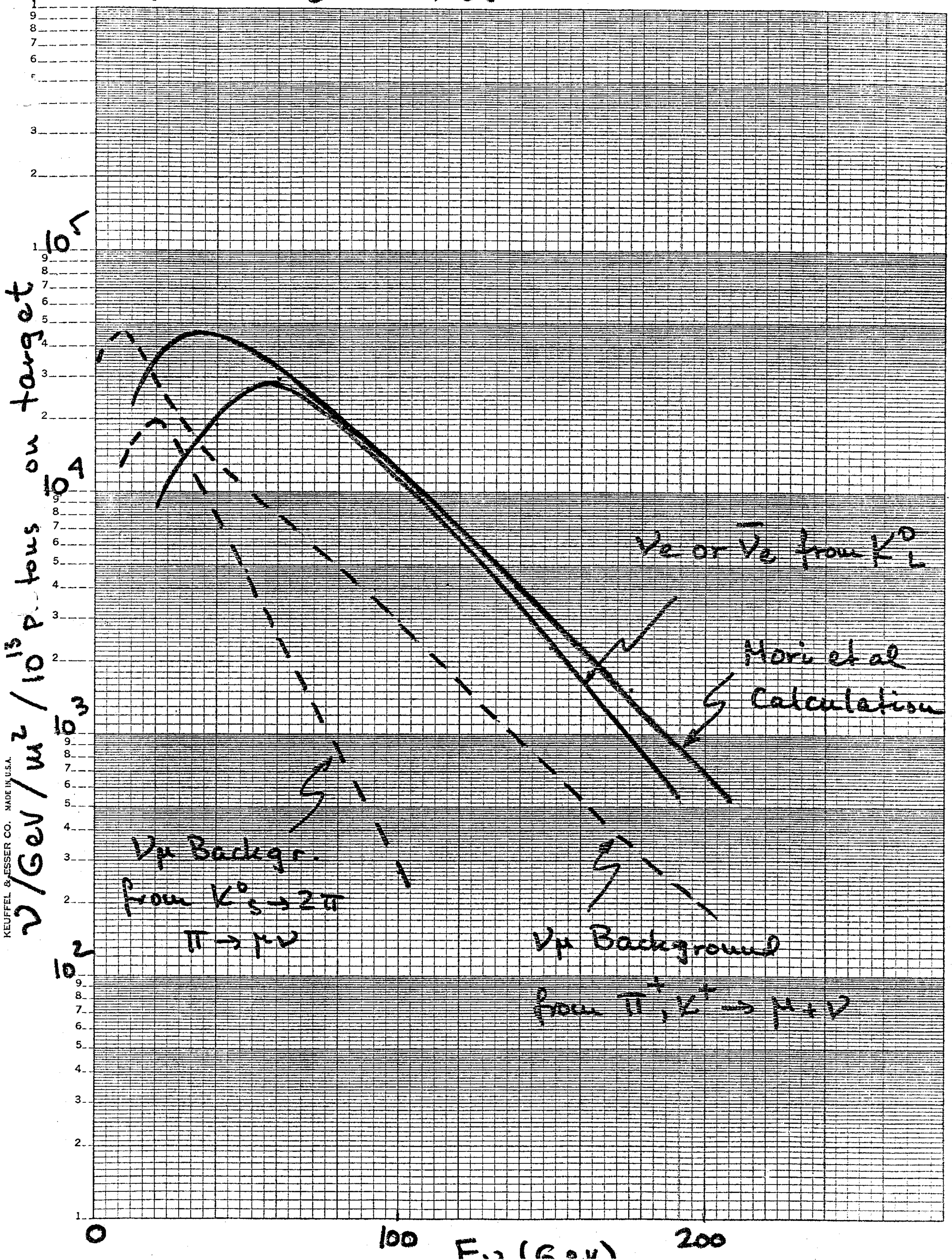
The muon-electron puzzle has been with us for many years. There are good experimental checks on muon-electron universality in the electromagnetic interactions (i.e., the μ^- and the e^- seem to have the same electromagnetic interactions). There is also experimental evidence in support of $\mu^\pm$-$e^\pm$ universality in the charged current weak decay interactions. There is very little experimental evidence about muon electron universality for other channels of ν_μ and ν_e interactions, and in particular, there is no experimental information at all on mu-e universality in the weak neutral current interactions.

We are proposing here a check of muon-electron universality by comparing both the charged and neutral current interactions of electron and muon neutrinos. We are placing particular emphasis on the universality check for neutral current interactions.

There is no hope of separating out the ν_e neutral current interactions from the ν_μ neutral current interactions in any of the existing neutrino beams since in these the ν_e flux is less than 1% of the ν_μ flux. As we will discuss in detail later, we can measure the ν_e neutral current interactions in the ν_e beams proposed here where the ν_e and ν_μ fluxes are approximately equal.

We feel that this measurement is of fundamental importance. Furthermore, several recent developments have moved this

ν_e and $\bar{\nu}_e$ Fluxes



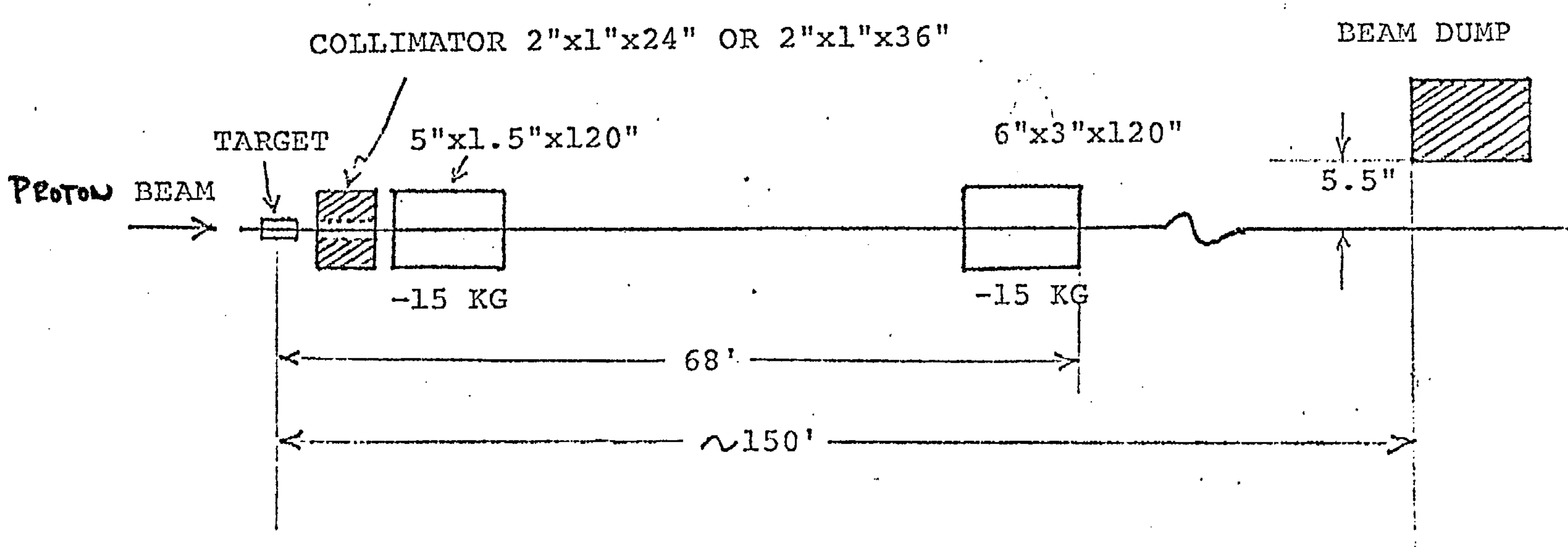


Figure 1.

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5 A. Pais, H. Georgi, Rockefeller Univ. Preprint 1974.

6 C. Baltay, B. Roe, Electron Neutrino Beams, 1973 Aspen Summer Study.

7 C. Baltay, B. Roe et al, Fermilab Proposal #296, March 1974.

8 S. Mori, S. Pruss, R. Stefanski, Fermilab Preprint TM 725 (April 1977).

h. Effect of full neon rather than NeH $h_1 = 1.5$, $h_2 = 4$.

Putting this together, we have

Case 1:

$200 * a_1 * b_1 * c_1 * d_1 * e_1 * f_1 * g_1 * h_1$

$200 * 5 * 2.7 * 1 * 0.11 * 0.67 * 1.8 * 1 * 1.5 = 540$

Case 2:

$10 * 5 * 2.7 * 2.2 * 0.32 * 0.67 * 1.8 * 1.7 * 4 = 780$.

Our Monte Carlo estimate was 750 neutrino events (plus 1/3 further anti-neutrino events) in reasonable agreement with the above. However, the overall accuracy of M-C and the above is about a factor of two.

d. (ν_e from K_o)/(ν_e from K_o+charged K) include horn enhancement, lifetime ratios, and branching ratios.

For case 1:

$$\nu_{K^\pm} \propto (0.15 \text{ flux} * 10(\text{horn}) + 0.04/10) *$$
$$0.0482(\text{b.r.})/1.2371(\text{lifetime}) \times 10^{-8}$$
$$= 59 \times 10^5$$
$$\nu K_L{}^o \propto (0.1) * 0.39/5.18 * 10^{-8} = 7.5 \times 10^5$$

Therefore $d_1 = 0.11$.

For case 2:

$$\nu_{K^\pm} \propto (0.15/10 + 0.04 * 10) * \frac{0.0482}{1.2371 \times 10^{-8}}$$
$$= 16 * 10^5$$
$$\nu_{K_L{}^o} \propto (0.1) * 0.39/5.18 * 10^{-8} = 7.5 \times 10^5$$
$$d_2 = 0.32 .$$

e. Effect of 2.5 mr cut. Estimate from previous Fermilab proposal and from assuming

$$dN/dp_\perp{}^2 \propto e^{-6\sqrt{p_\perp{}^2+m^2}}$$
$$e = 2/3 .$$

f. Effect of horn absorption (from Monte Carlo calculations).

$f = 1.8$.

g. Effect of plug

$g = 1$ (no plug)

$g_2 = 1.7$. The raw rate in the EMI, ionization chambers in beam and events in the bc goes up by about a factor of 3 with plug removed. However, a large part of this is due to neutrino, not anti-neutrino events.

APPENDIX

A. Estimate of Electron Neutrino Flux from Existing Data (E-53A and E-180)

We now have some initial experimental evidence for the electron neutrino flux.

1. In the ν(Ne-H) experiment E-53, some 200 events with no muon but an electron at the primary vertex are found. Here some 50,000 pictures were taken using the two-horn neutrino beam with no plug, with 10^{13} protons/pulse at 400 GeV. A heavy neon mix was used.

2. In the $\bar{\nu}$(Ne-H) experiment E-180, some 10 events with no muon but an electron at the primary vertex are found. Here some 50,000 pictures were taken at 300 GeV using the two-horn neutrino beam with plug with 10^{13} protons per pulse. A light neon mix was used.

Although many fewer events are found in the second run, the background correction for charged kaon $\rightarrow \pi e \nu$ is smaller and both estimates are relevant. We wish to convert this to an exposure of 250,000 pictures with 2.7×10^{13} incident protons/pulse in an electron neutrino beam.

There are a number of conversion factors:

a. picture ratio $a = 250\text{ K}/50\text{ K} = 5$,

b. proton intensity ratio $b = 2.7/1 = 2.7$,

c. ratio from changing primary proton energy. This ratio is taken from our previous Fermilab proposal,

c case $1 = c_{\nu\mathrm{Ne}} = c_1 = 1 \qquad c_{\bar{\nu}\mathrm{Ne}} = c_2 = 2.2$.

There will also be systematic errors due to classifying events as NC or CC which we estimate to be less than 10%. It is then reasonable to expect the total error to be about 15%.

of this experiment is that the results are independent of K_L^o flux or background flux calculations. We use only the measured numbers of charged current interactions and the total number of neutral current events.

TABLE II

	Events
$\nu_e N \to e^- X$	750 *
$\nu_e N \to e^+ X$	250 *
$\nu_e N \to \nu_e X$ + $\bar{\nu}_e N \to \bar{\nu}_e X$	290
$\nu_\mu N \to \mu^- X$	1050 *
$\bar{\nu}_\mu N \to \mu^+ X$	300 *
$\nu_\mu N \to \nu_\mu X$, $\bar{\nu}_\mu N \to \bar{\nu}_\mu X$	380
Total Neutral Current Events	670 *

* Indicate numbers we expect to measure in experiment.

We would be sensitive to a neutron contamination. However, a 10 GeV visible energy cutoff reduces our signal by only a very small amount. Results from previous experiments indicate an extremely small residual high energy neutron flux. We would be able to check this experimentally by examining the number of events as a function of chamber position. (The interaction length in pure neon will be about 80 cm.)

IV. Estimate of the Error on the NC/CC Ratio for Electron Neutrinos

Using the number of charged current events on Table I, and the NC/CC ratios of 0.25 and 0.40 for ν_μ and $\bar{\nu}_\mu$, respectively, we estimate the number of neutral current events expected in this experiment, assuming ν_e, ν_μ universality to illustrate the method. These numbers are shown on Table II. We cannot distinguish NC events from ν_e, $\bar{\nu}_e$, ν_μ and $\bar{\nu}_\mu$, but measure their sum. We can, however, distinguish the CC events by identifying e^-, e^+, μ^- and μ^+ in the heavy neon. We thus expect to measure the five numbers that are starred on Table II. From these five measured numbers, we can calculate the number of ν_e and $\bar{\nu}_e$ induced neutral currents by subtracting the ν_μ and $\bar{\nu}_\mu$ induced neutral currents, which we calculate from the actually observed number of ν_μ and $\bar{\nu}_\mu$ CC events, and the NC/CC ratios for ν_μ and $\bar{\nu}_\mu$. (We assume that these ratios will be measured in other ν_μ and $\bar{\nu}_\mu$ experiments to an accuracy better than we need here.) Thus we will obtain for the numbers on Table II:

$$\begin{aligned} NC(\nu_e,\bar{\nu}_e)_{experiment} &= 670 - (0.25*1050+0.40*300) \\ &= 290 \pm 30 \quad . \end{aligned}$$

We will be able to compare this with the number of these events expected if ν_e, ν_μ universality holds by using the observed number of events with e^- and e^+.

$$NC(\nu_e,\bar{\nu}_e)_{universality} = 0.25 * 750 + 0.40 * 250 = 290 \pm 17 \; .$$

We could then obtain a ratio: $\dfrac{NC(\nu_e,\bar{\nu}_e)_{experiment}}{NC(\nu_e,\bar{\nu}_e)_{universality}} = 1.0 \pm 0.12.$

These errors are statistical only. We expect, however, that the statistical errors will dominate the systematic errors due to energy cutoff and other problems. A very important feature

TABLE I

Number of charged current neutrino events in a 20 m^3 pure neon filled bubble chamber for an exposure of 250,000 pictures with 10^{13} interacting protons per pulse (2×10^{13} incident protons per pulse).

$\nu_e N \rightarrow e^- X$	750
$\bar{\nu}_e N \rightarrow e^+ X$	250
ν_μ (from K_L^o) $N \rightarrow \mu^- X$	500
$\bar{\nu}_\mu$ (from K_L^o) $N \rightarrow \mu^+ X$	175
ν_μ (from K_S^o) $N \rightarrow \mu^- X$	100
$\bar{\nu}_\mu$ (from K_S^o) $N \rightarrow \mu^+ X$	50
ν_μ (from π^+, K^+) $N \rightarrow \mu^- X$	450
$\bar{\nu}_\mu$ (from π^-, K^-) $N \rightarrow \mu^+ X$	75
Total $\nu_\mu N \rightarrow \mu^- X$	1050
Total $\bar{\nu}_\mu N \rightarrow \mu^+ X$	300

a) The first bending magnet could be replaced by a dipole magnet with a smaller aperture and a higher field. This could reduce the ν_μ background by as much as a factor of two.

b) The ν_e fluxes could be increased by as much as a factor of 4 by going to a shorter beam, like a 250 meter decay path with a 250 meter shield.

We will continue to explore these possibilities further if this proposal were to be looked at with favor.

Using a Monte Carlo program, we have calculated the ν_e and $\bar{\nu}_e$ fluxes in this beam, as well as the "background" ν_μ and $\bar{\nu}_\mu$ fluxes from the $\pi^\pm \to \mu\nu$, $K^\pm \to \mu\nu$, and $K_S^o \to \pi^+\pi^-$ followed by $\pi^\pm \to \mu\nu$ decays. These fluxes, shown in Fig. 2, are in reasonable agreement with those calculated by S. Mori et al for the same beam.[8] The ν_e fluxes in this beam are comparable to those in our previous more elaborate design, but the background ν_μ fluxes are an order of magnitude higher (in the elaborate beam these backgrounds were less than 10% of the $\overset{\vee}{\nu}_e$ flux while in this simple beam, the two are roughly the same). However, as will be discussed in more detail later, this background is tolerable for the purposes of the measurement proposed here, and we feel that the existing sign selected beam would be useful for this experiment.

The number of neutrino interactions we would obtain in this experiment using this beam is given in Table I. These numbers are in reasonable agreement (within a factor of two) with what we would expect from the numbers of ν_e interactions we have actually observed in experiments E-53A and E-180. The details of this extrapolation are given in Appendix I.

We thus feel that the existing sign selected beam would be adequate for the purposes of this proposal. However, we are considering two possible improvements:

III. The Electron Neutrino Beam

The source of the neutrinos in this beam is the decays:

$$K_L^o \to \pi^- e^+ \nu_e$$
$$\to \pi^+ e^- \bar{\nu}_e$$
$$\to \pi^- \mu^+ \nu_\mu$$
$$\to \pi^+ \mu^- \bar{\nu}_\mu \quad .$$

The dominant ν_μ flux from the two body decays, $\pi^{\pm} \to \mu\nu$ and $K^{\pm} \to \mu\nu$, is suppressed by a large factor by following the target with a small angle collimator and a dipole magnetic field which sweeps out the $\pi^{\pm}$ and $K^{\pm}$ before they decay. Such a beam would contain roughly equal numbers of the four kinds of neutrinos, ν_e, $\bar{\nu}_e$, ν_μ, and $\bar{\nu}_\mu$, instead of the $\nu_e/\nu_\mu = 1/200$ ratio in the existing neutrino beams.

We originally examined the possibility of such a beam in the 1973 Aspen Summer Study[6] and later carried out a more detailed design of an elaborate ν_e beam.[7] Recently, we have considered the possibility of using the existing sign selected bare target beam,[8] which consists of a target, a collimator, two dipole magnets, and a beam dump. The two bending magnets can easily be moved in line with the center line of the beam and their fields set to sweep in the same direction to suppress the two-body $\pi^{\pm}$ and $K^{\pm}$ decays (see Fig. 1).

II. The Detector

We believe that the 15 ft bubble chamber filled with heavy neon is an ideal detector for this experiment. Both of our groups have experience in electron and muon detection in this chamber and fill (E-53A and E-180). We believe that we have shown that we can clearly isolate events with a single e^+ or e^-. The Dalitz and Compton backgrounds are not a problem even with the large background of ν_μ interactions. In the proposed experiment, the number of interactions producing e's and μ's are about the same (compared to 1 in 200 in E-53A and E-180). With the 30 kG magnetic field, we have been able to separate e^+ from e^- over the energy range of interest here. We thus feel confident that we can separate events with e^+, e^-, μ^+, or μ^-, clearly from each other. We know of no other type of detector, existing or contemplated, with these features, which are crucial in allowing us to make this measurement.

The main experimental problem will be the separation of the neutral current events from neutron and K^o induced background . Experience with previous experiments (E-45 and others) indicates that this is not a problem if a cut on the visible energy $E_{vis} \geq 10$ GeV or so is made.

measurement from the "long shot" or "someone ought to do it sometime" category to one of great current interest and urgency. One is the (probable) discovery of heavy leptons.[1,2] If these come in electron and muon types, which may very well have different masses, then they will cause differences in ν_e and ν_μ interactions. The second is the apparent non-observation of e^- neutral current interactions in atomic physics experiments[3,4] (optical rotations in bismuth, etc.). This, naively thinking, raises the question that if the ν_μ and e^- have different neutral current interactions, is it true that a) the ν_μ and μ^- N.C. interactions are the same, but both of them different from ν_e and e^- N.C. interactions, or b) the ν_μ and ν_e N.C. interactions are the same, but both of them different from μ^- and e^- N.C. interactions, or c) neither of the above. It seems to us that an experimental measurement of the ν_e neutral current interactions is of great interest at this time. Even the relatively crude 10 to 20% measurement we are proposing here could be quite significant since the differences could be large (i.e. the atomic physics experiments set limits on e^- neutral currents about an order of magnitude below the Weinberg model predictions. Also, various theoretical models, such as the one of Pais and Georgi,[5] would suggest large deviations from universality.).